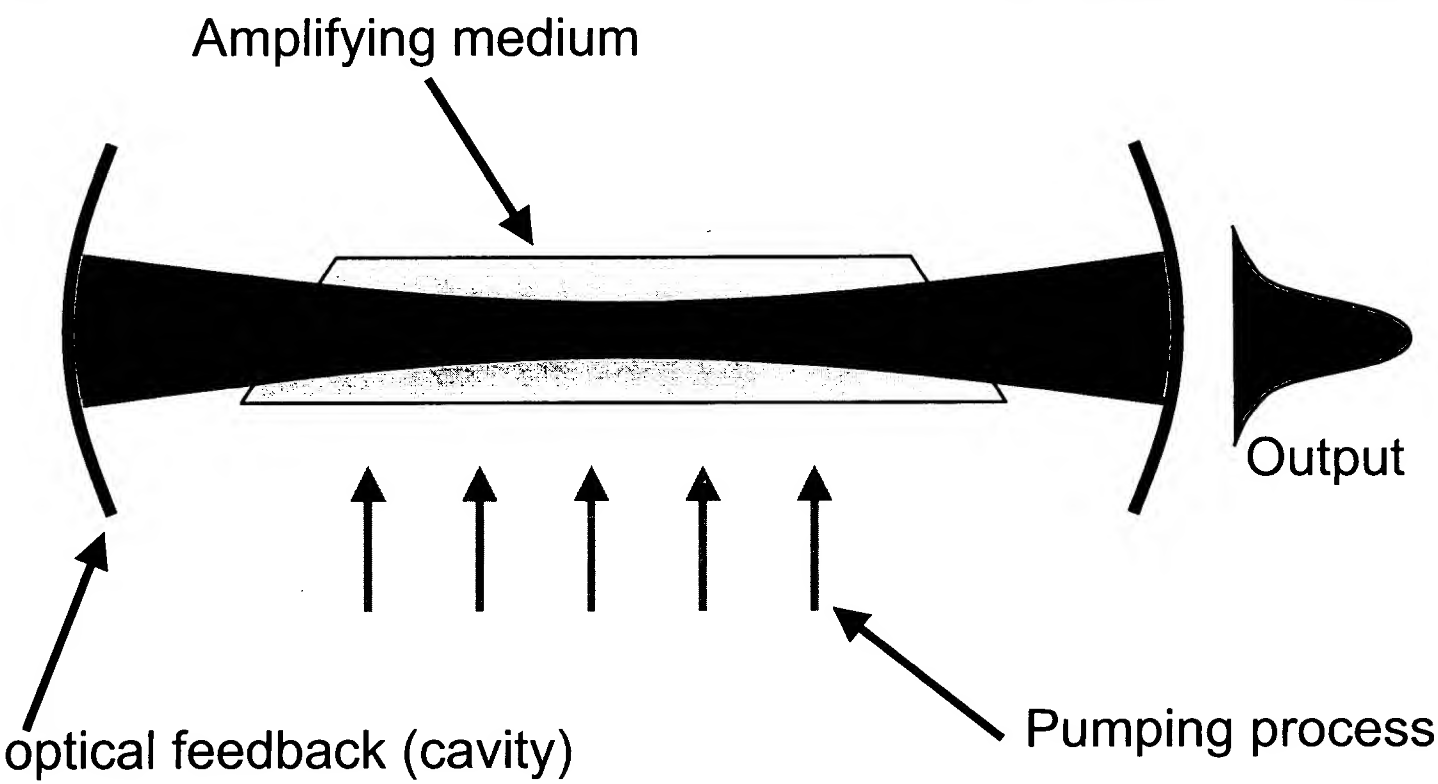
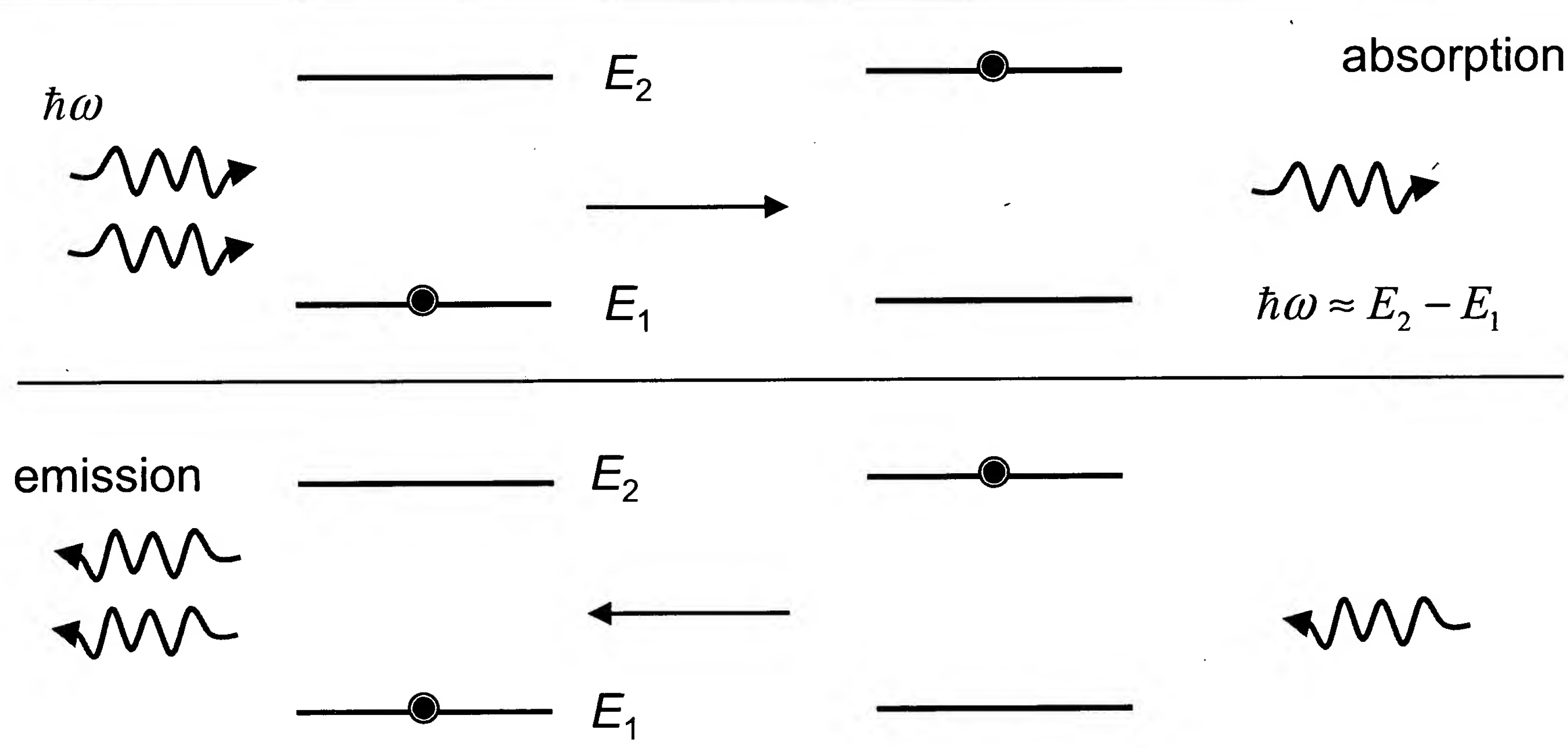
Three key elements in a laser



- Pumping process prepares amplifying medium in suitable state
- Optical power increases on each pass through amplifying medium
- If gain exceeds loss, device will oscillate, generating a *coherent* output

Acknowledgements to O. Solgaard for this figure

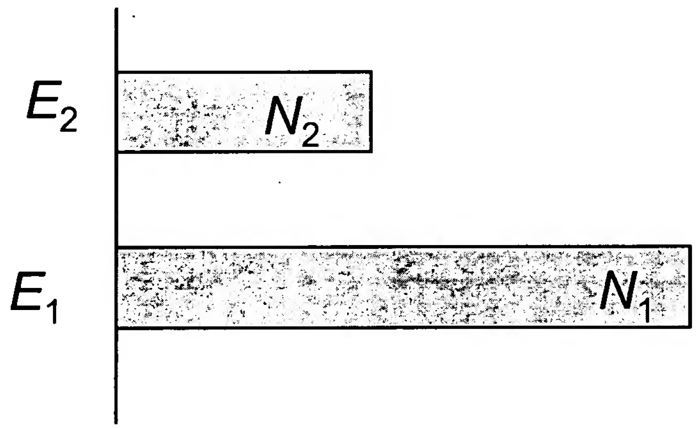
Amplifying Medium



- Laser amplification relies on *stimulated emission*
- Rates are proportional to number of photons, and to atomic populations
- If stimulated emission rate exceeds absorption rate, net optical gain
- Need *population inversion* to get gain
  - must have more population in excited state than in lower level

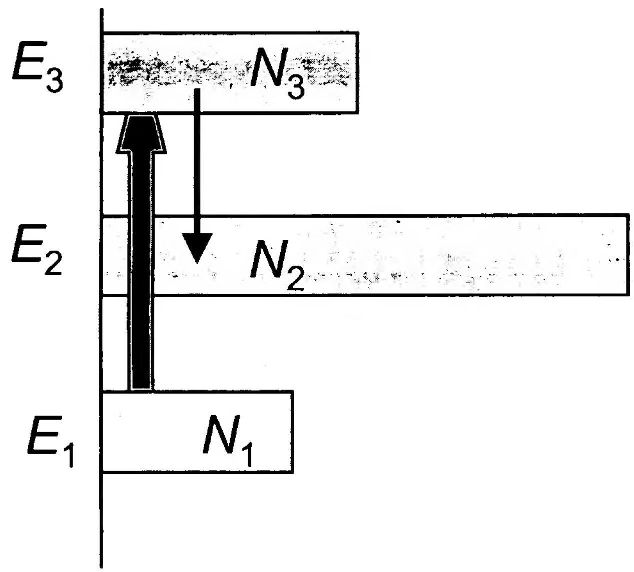
Pumping Mechanism

- In thermal equilibrium, populations follow Boltzmann ratio
  - cannot produce a population inversion



$$\frac{N_2}{N_1} = e^{-(E_2-E_1)/kT}$$

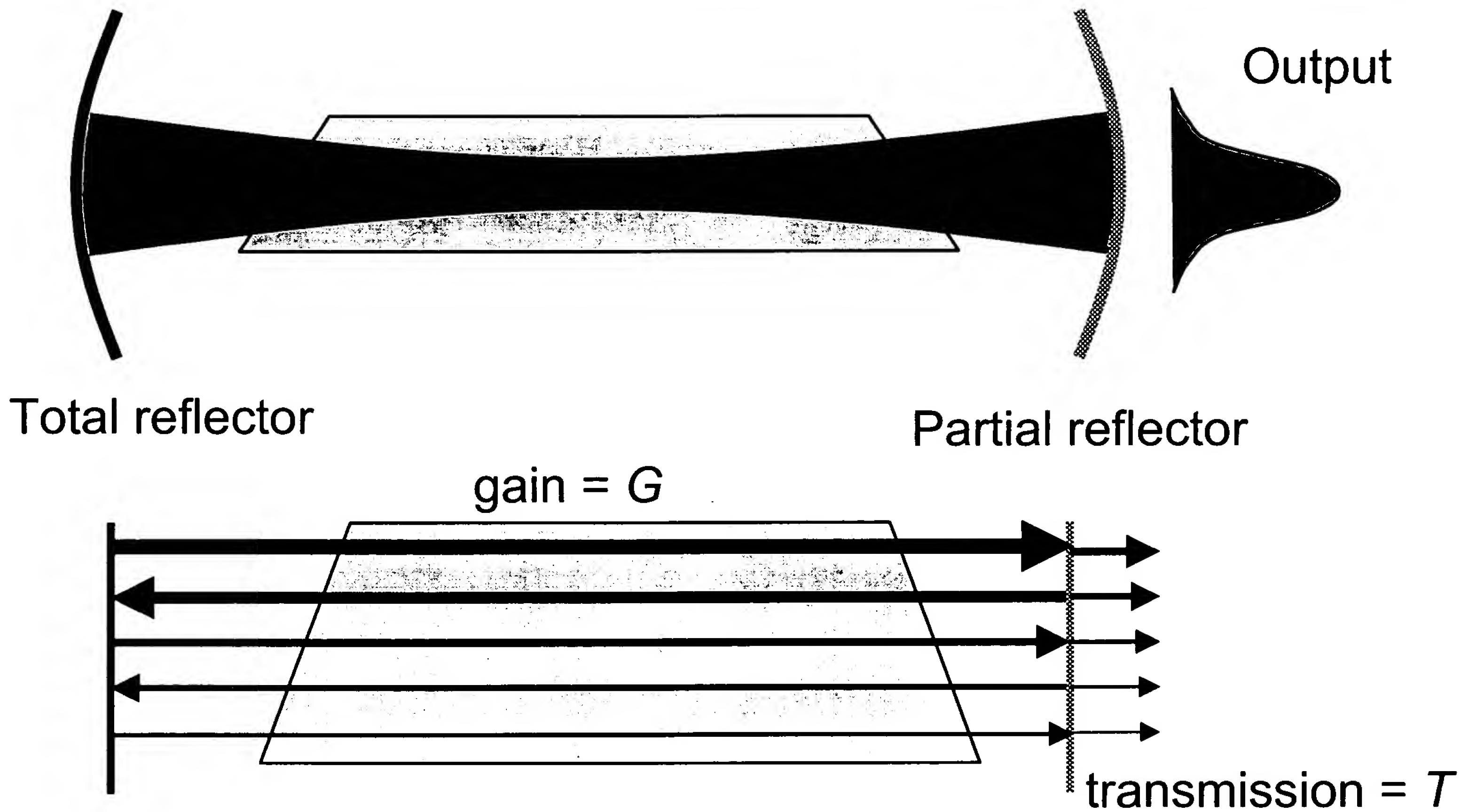
- Energy input from pump source necessary to get inversion



pump excites population selectively to upper laser level

populations depend on relaxation rates

Feedback in an Optical Cavity



- Each successive pass grows or shrinks depending on $G \gtrless T$
  - can picture as Fabry-Perot interferometer
- Curved mirrors lead to Gaussian transverse intensity dependence

Must understand three broad topics

- How does radiation interact with matter?
  - absorption and emission
  - stimulated and spontaneous events
  - conditions for amplification rather than absorption

- How do we prepare system to obtain gain
  - dynamics of evolution of population between quantum levels
  - pumping to obtain population inversion
  - saturation to reach steady-state

- How do EM waves propagate in space and resonate in cavities
  - gaussian beams
  - interferometers (optical feedback cavities)

- Combining these basic elements, we can predict behavior of laser oscillators and amplifiers

What properties make lasers interesting/useful?

- Compared to conventional “thermal” light source:
  - key difference is “coherence” of the laser output
  - highly correlated in space and time

- Spatial coherence
  - laser beam diverges slowly, ideally at “diffraction limit”
  - propagate long distances: $\theta \sim \lambda / w$
  - focus to small ($\sim \lambda^2$) spot

- Temporal coherence
  - nearly ideal sine wave
  - very precise measurements of distance and time possible

- Extremely short pulses possible
  - < 5 fs (~ one optical cycle)

- Extremely high power possible
  - petawatt peak power systems demonstrated ($> 10^{15}$ W)
  - kilowatt average powers widely used commercially

Types of lasers

- Classify by gain medium

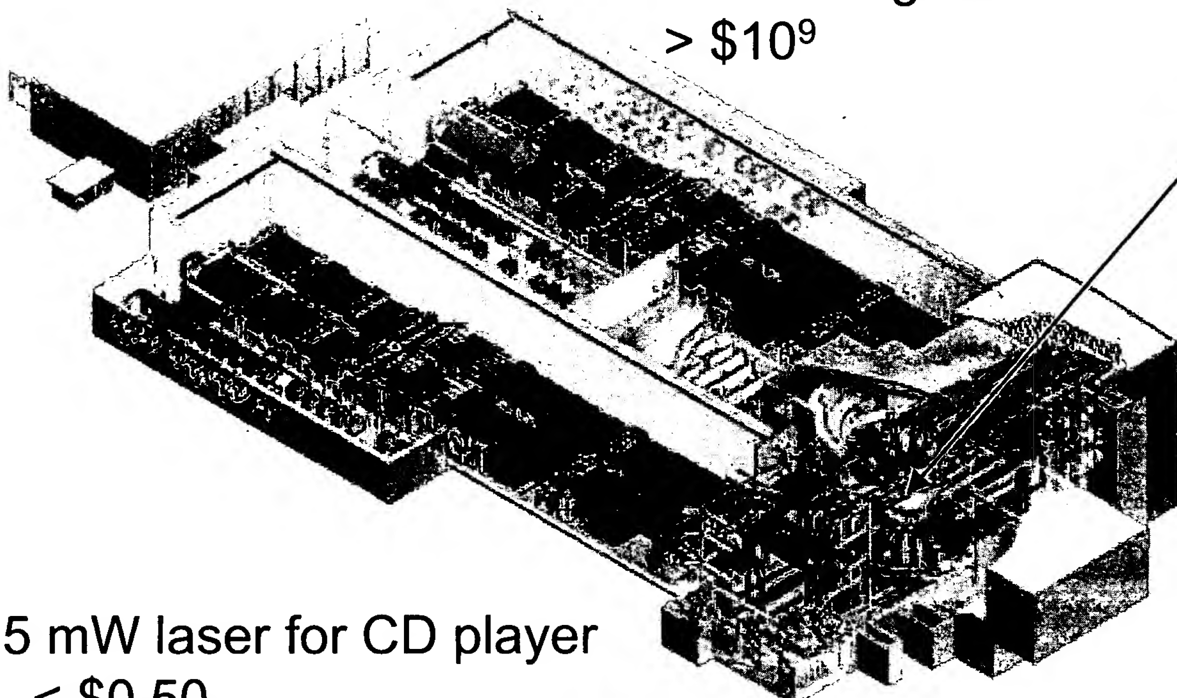
- Gas lasers
  - electron impact excites atomic or molecular species
  - usually low efficiency (10^{-4} typical), discrete wavelengths (UV – FIR)
  - He-Ne, Ar-ion, CO_2, …

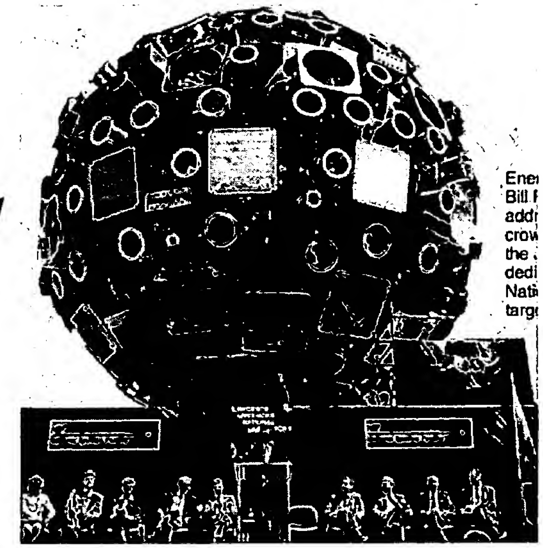
- Solid-state lasers
  - optical pumping (flashlamp, diode laser) excites dopants in solids
  - efficient, high power, often broadly tunable and/or short pulses (typically NIR)
  - Nd:YAG, Ti:sapphire, …

- Semiconductor diode lasers
  - current injected into diode junction creates inversion
  - small (< mm^3), efficient, easily modulated
  - AlGaAs, InGaAsP, AlGaN, …(typically NIR, recently FIR – UV)

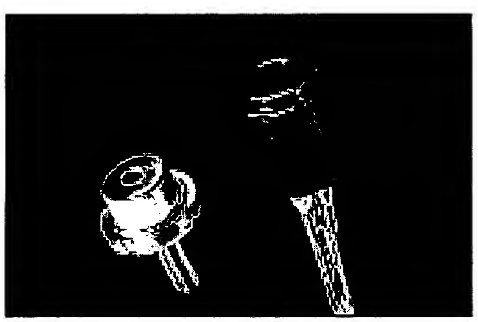
Huge range of laser devices

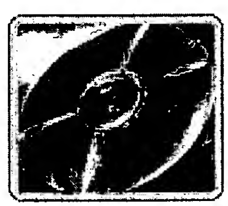
National Ignition Facility
1.8 MJ Nd:glass laser
> $$10^9$





5 mW laser for CD player
< $0.50





All operate on
same general principles